Force and Motion

What is Physics?

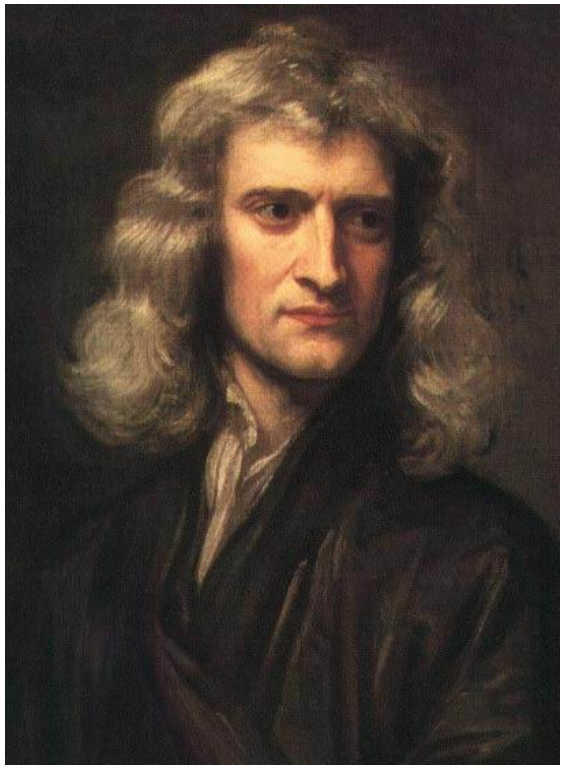
- Study of the nature of the Universe
  - what the Universe is made of – Matter
    - stars and planets and galaxies
    - different forms like gases and liquids and solids
    - sub-atomic particles like protons and electrons
    - light and radiation
  - and how this 'stuff' behaves – Forces, Motion, Energy
    - how does a rocket get to outer space?
    - how can a bicycle stay upright on such thin tires?
    - how do protons and electrons make atoms, and atoms make molecules, etc?
    - how did the Universe as we know it come to be?

What we do at Fermilab?

- Study how the Universe works
  - accelerate protons to near speed of light and smash them into each other
  - see what happens in giant detectors
  - has anyone ever been to Fermilab?

Newton's Laws

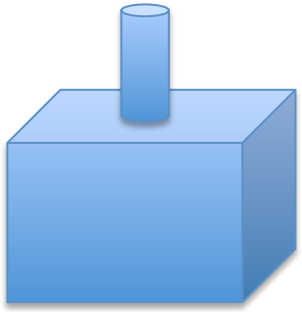
- Physics began a long time ago. . .
- Why is Issac Newton famous? An apple fell on his head??



Newton's Law 1 – the glass/tablecloth

- Newton discovered the rules of force and motion

1. objects at rest stay at rest; objects in motion stay in motion
   - "Inertia" = resistance to change in motion/rest
   - "Force" = something applied to overcome an object's inertia and change its motion
     - » push, pull
     - » also gravity, magnets, electric charge



glass & tablecloth

Newton's Law 2

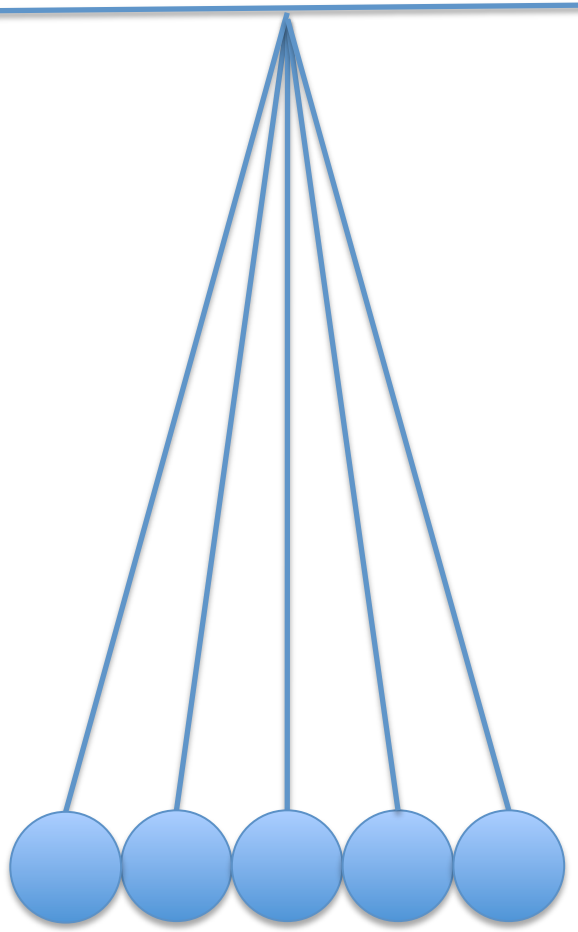
- Newton discovered the rules of force and motion

2. F = ma the amount of force needed to speed up an object depends on how massive it is.

$$Inertia \propto mass$$

Newtonian Demonstrator

- pull back 1 ball
- pull back two balls
- one ball on each side
- show works at any scale



Momentum

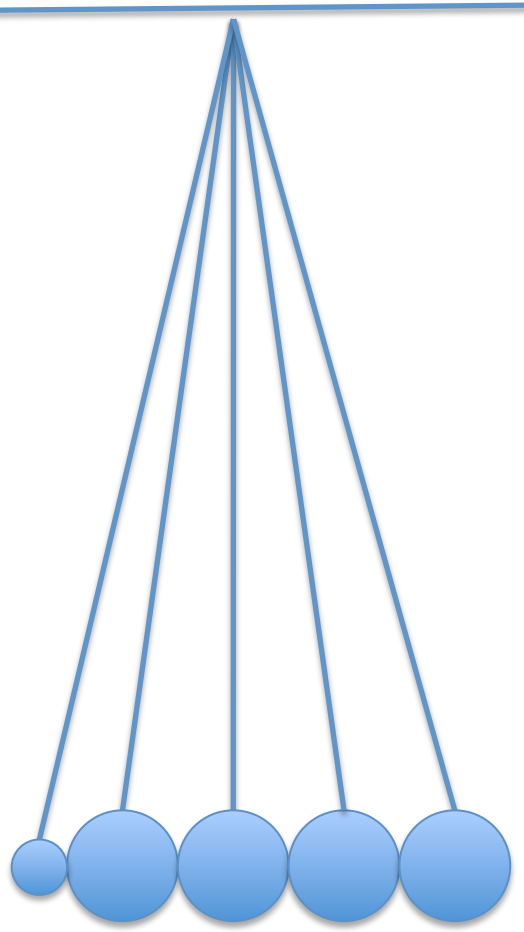
- moving objects have momentum
- amount of momentum depends on *mass and velocity*
- total *momentum is always conserved*
- also can be *transferred* between objects

$$momentum = m * v$$

Newtonian Demonstrator

- what about replacing last ball with a smaller one?
- conservation of momentum

$$mV = Mv$$



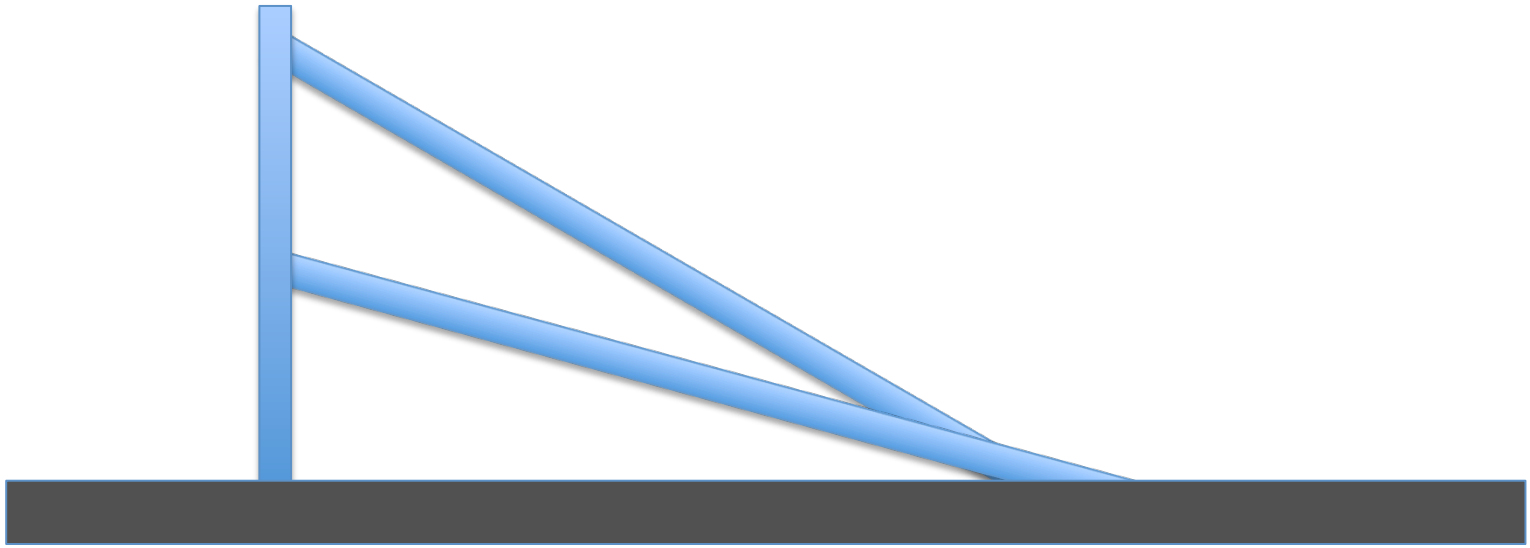
Gravity

- Gravity is the pull of the Earth on all objects which makes them fall
- actually, all massive objects pull on each other, but the masses are too small to notice

$$Gravity \propto mass$$

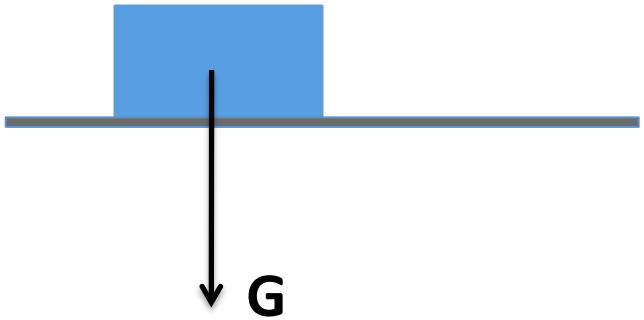
Ramps & Skateboards

- use ramps and skateboards to show that:
  - *mass does not matter* (force is larger, but so is inertia)
  - *angle does matter* (put heavier one on steeper board then on less steep board)

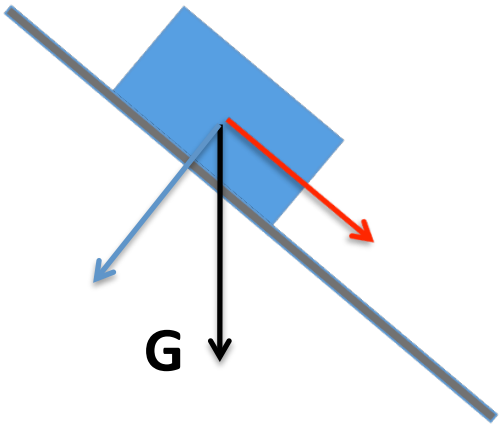


Gravity

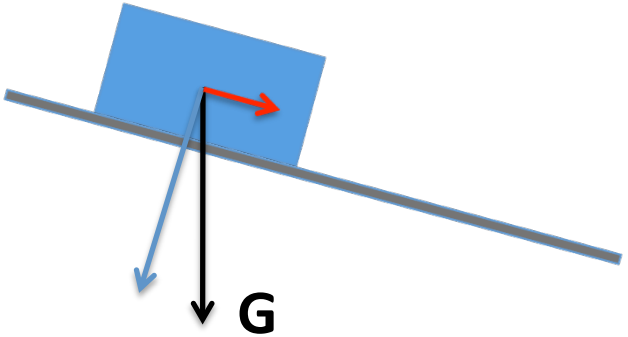
doesn't move



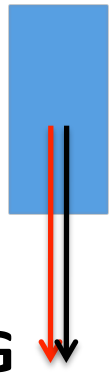
moves faster



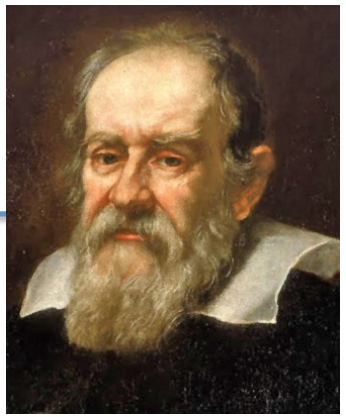
moves slowly

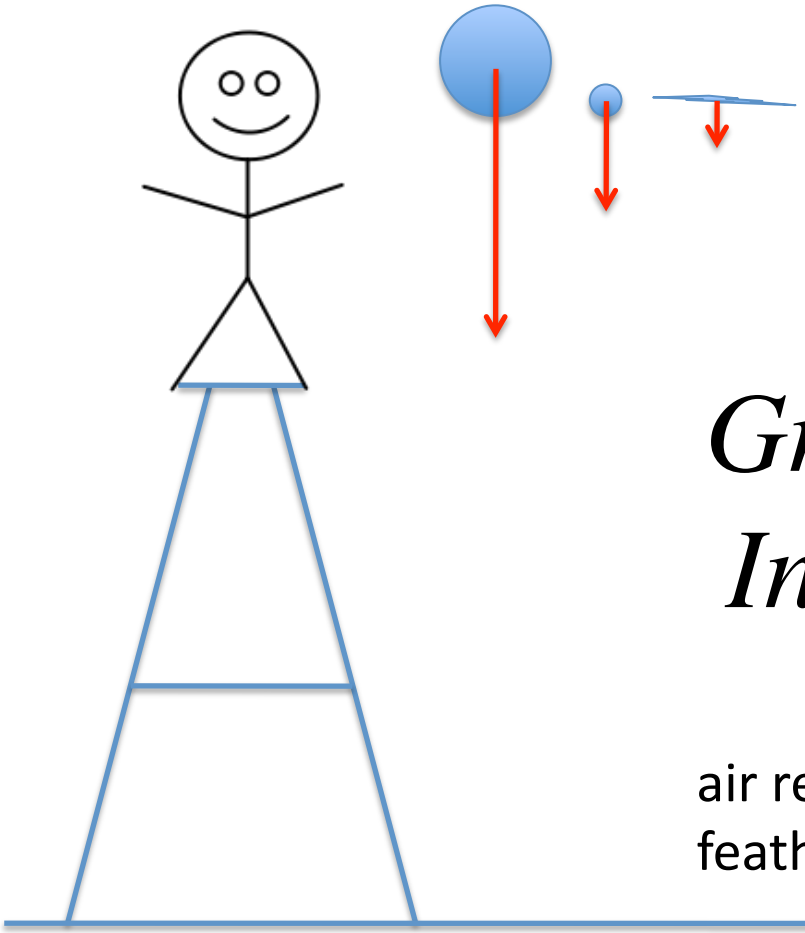


moves fastest



Gravity





mass doesn't matter!!

Galileo discovered that ~400 years ago

$$Gravity \propto mass$$

$$Inertia \propto mass$$

air resistance: Moon hammer & feather video

Rotational Motion / Rolling Objects

- *Moment of Inertia* – resistance to change in rotation rate
  - two open cylinders (different mass)
  - open cylinder vs. solid bar (same mass)
  - solid bar vs. solid disk (same mass)
  - race all three
  - sphere is fastest
  - what about a hollow sphere vs. a solid sphere?

It's the Distribution of Mass that matters!!

Figure Skater / Chair

- this is exactly the principle that allows a *figure skater* to spin so fast and to change their speed of rotation

- try it with a *spinning chair*, a student and a few small weights

Angular Momentum

- rotating obects have *angular momentum*
  - amount of momentum depends on *location of mass and rate of rotation*
  - total *angular momentum is always conserved*
  - also can be *transferred* between objects

Bike Wheel / Lazy Susan

- bike *wheel remains vertical*, precesses

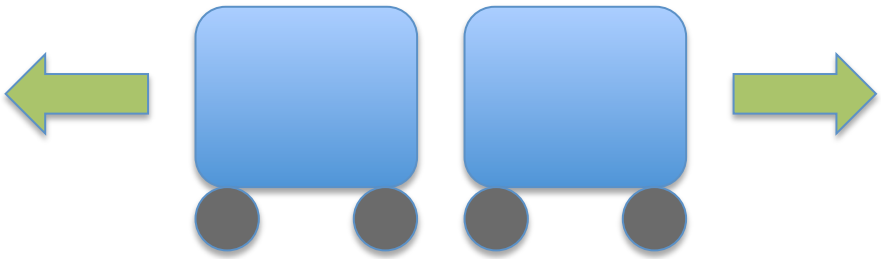
- transfer of angular momentum – *student on the lazy susan* with spinning bike tire

Newton's Law 3 – kids on skateboards

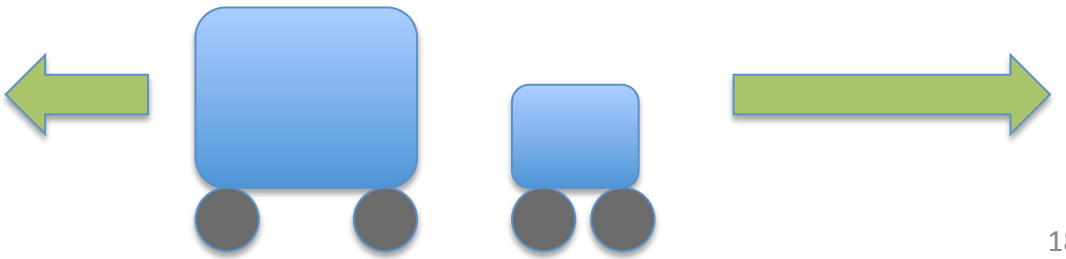
- Newton discovered the rules of force and motion

3. for every action there is an equal and opposite reaction

can show with
2 students on
scateboards
one pushes!
then the other!



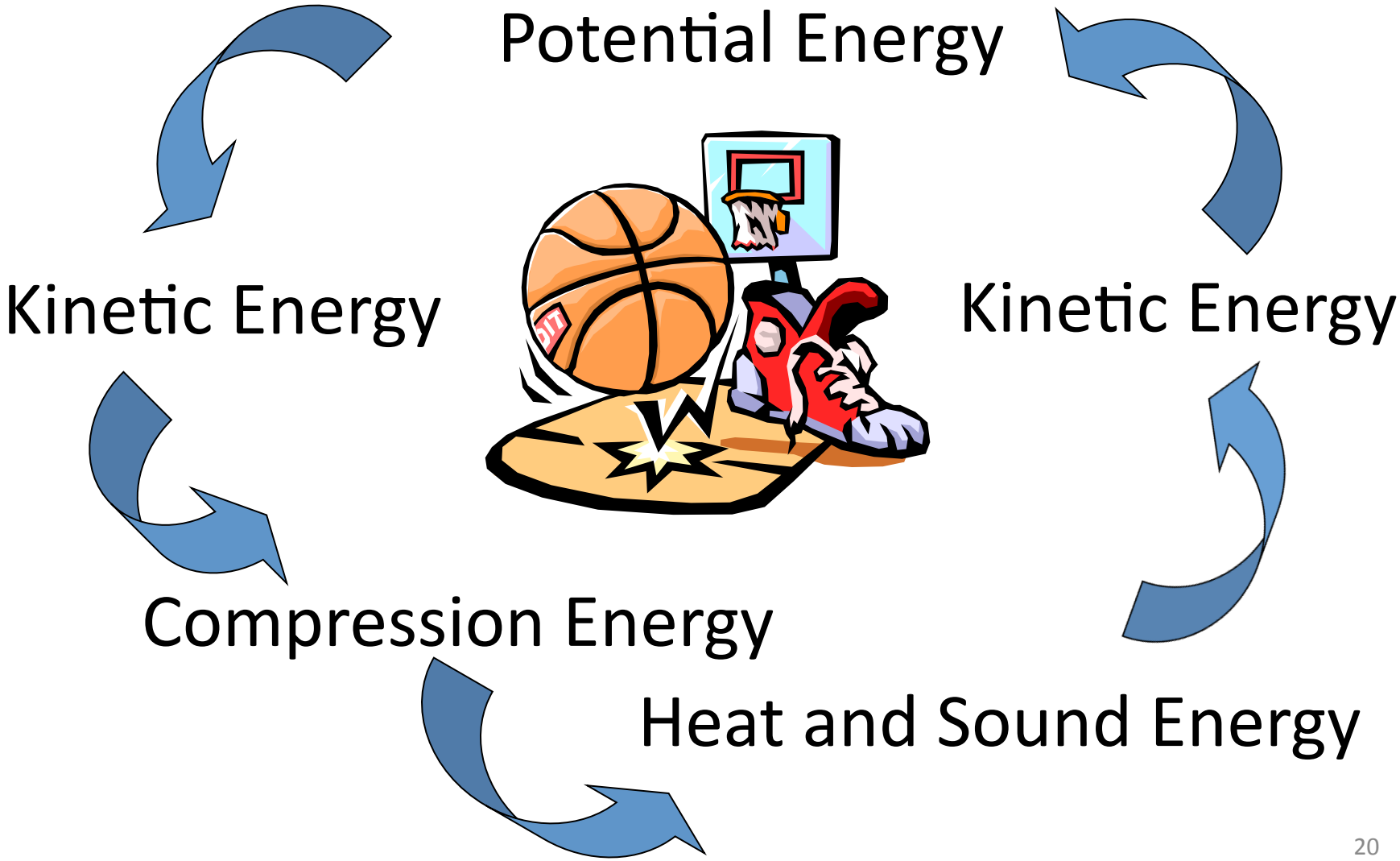
can show with
student and adult
on scateboards



Energy

- everything has energy
- total *energy is always conserved*
- but can be *transferred between different objects or different forms*
  - potential energy
  - kinetic energy
  - heat energy
  - sound energy
  - electromagnetic energy
  - . . .

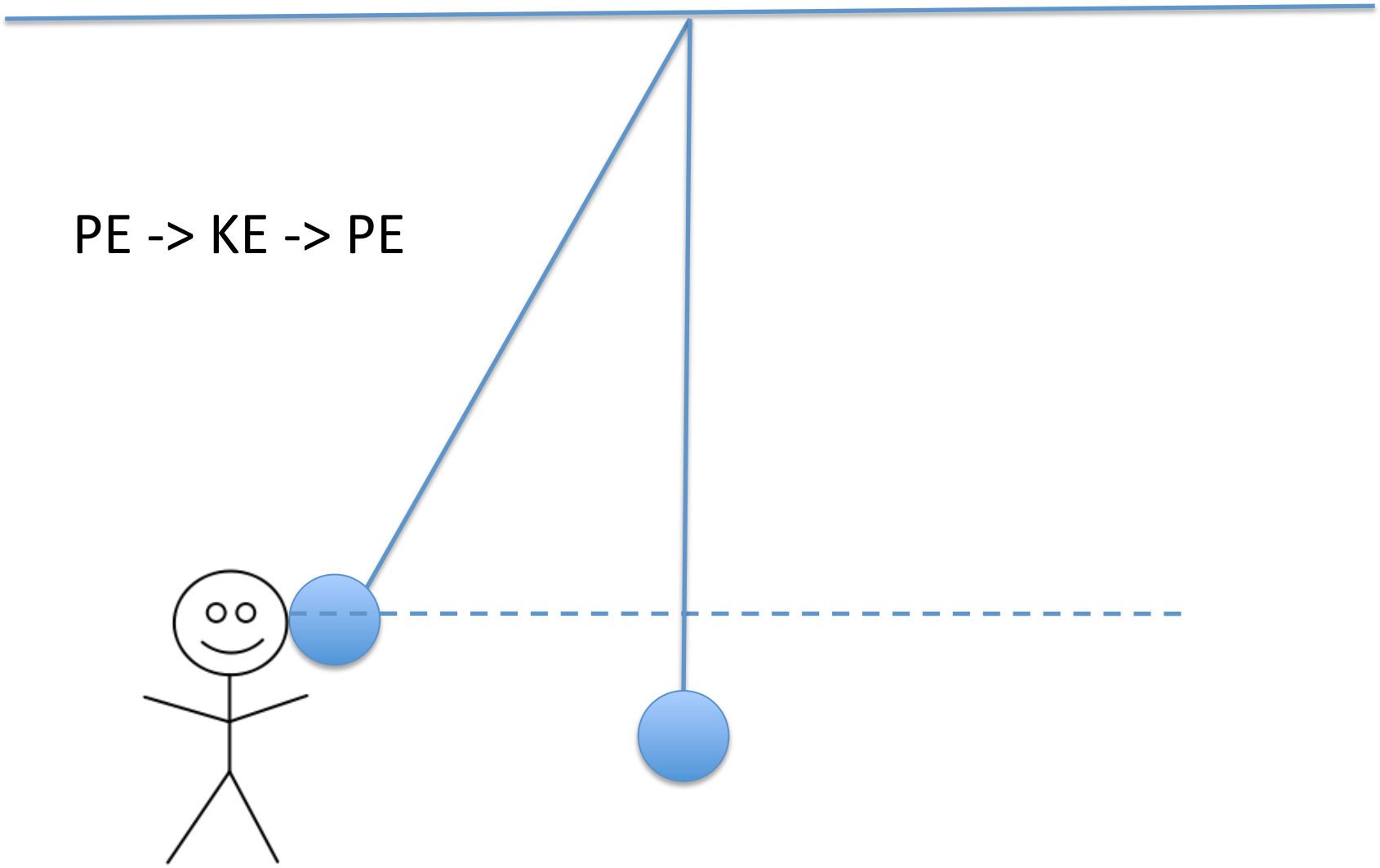
Conservation of Energy



Conservation of Energy

- where does the energy come from to:
  - *sail a sailboat?*
  - *make plants grow?*
  - *drive a car?*
  - *when a ball falls and speeds up?*
  - *cook toast?*
  - *…*

Pendulum



What did we learn today?

- Inertia
  - Moving things stay moving, stationary things stay stationary
  - unless you apply a force
- Gravity
  - mass doesn't matter – angle matters
- Rotating objects are different
  - shape matters
- Some things don't change and that's very useful for understanding
  - momentum, angular momentum, and energy